Chapter 3
Outlet Works Design

3-1. General

a. Summary. This chapter presents discussion and guidance on the concrete and foundation properties generally considered in design, the loads and load conditions typically applied to outlet works intake towers, and various other information on stability analysis and structural design. Design and load conditions of the intake structure operating components and appurtenant features are discussed in Chapters 5 and 6.

b. Structural design. The structural design should be developed in conjunction with the hydraulic design to provide a stable, load-resistant structure which meets all functional and structural performance requirements. Structural elements of the intake structure should be sized and proportioned to resist the various load conditions that will be imposed during construction and operation. The structural design and geotechnical conditions at the site must be closely coordinated.

c. Stability. Initial layouts are followed by a stability analysis. If the structure fails to meet criteria, the layout is modified and reanalyzed. This process is repeated until an acceptable configuration which meets stability criteria for all load conditions is attained.

d. Strength, serviceability, and dam safety. Outlet works structures must be designed for strength and serviceability and to protect the project against potential latent deficiencies that could jeopardize dam safety.

(1) The structure strength must be sufficient to provide the required margin of safety for all possible loads and load conditions. Serviceability means the structure is watertight and resistant to potential damage from cavitation or abrasion erosion and is adequately protected against corrosion of reinforcing steel, embedded steel, and exposed steel components.

(2) The possibility of upstream ground slope instability due to floods or earthquakes should be taken into account during the design of the outlet works. During a major flood or earthquake, the ground slopes upstream of the project may become unstable causing landslides and the accumulation of large quantities of debris and sediment at the outlet works entrance. The configuration of the approach and approach walls should minimize the potential for sediment and debris accumulation which could block the outlet works entrance. Provisions should be made to allow for removal of debris and sediment that could accumulate at the outlet works entrance.

(3) Major floods and earthquakes can be catastrophic to lifelines. Roads, bridges, electrical power, and communications are necessary to respond quickly to an on-project emergency condition. The protection of project lifelines important to operation of the intake/outlet works should be provided for during design.

(4) Leakage from the outlet conduit or along the conduit/dam interface for cut-and-cover conduits can lead to slope instability at critical abutment areas and at the embankment dam. The intake structure/conduit layout and design should protect against any such deficiencies that might jeopardize dam safety.

3-2. Design Data

a. Concrete properties. Concrete properties normally used to design intake structures include the unit weight; compressive, tensile, and shear strengths (friction and cohesion); Young's modulus of elasticity; and Poisson's ratio. Mass concrete structures that require thermal studies to assess the effects of stresses induced by temperature changes in the concrete require thermal properties which include conductivity, thermal

diffusivity, specific heat, and the coefficient of thermal expansion. In structures that are designed to pass sediment, trash, or other debris, special high-strength concretes such as silica fume concrete may be utilized to provide highly abrasion-resistant surfaces.

b. Foundation properties. The principal foundation properties for outlet works design are bearing capacity, deformation and elastic modulus, and shear strength. These properties determine suitability of the rock mass to support the structure placed on it and the resistance to sliding at the structure/foundation interface. Dynamic elastic modulus and shear strength are important factors in the seismic design of these structures. Also very important to stability analysis is whether any weak zones exist within the foundation where sliding failure could occur. Such zones may consist of shears, faults, or other discontinuities along which material of low strength such as clay gouge may be present in an otherwise sound rock mass. Significant voids such as those produced by dissolving of some limestone formations also influence foundation suitability. The foundation properties must be investigated early in the design phase of the project to determine design parameters and any remedial treatment that may be necessary during excavation and construction. The structural design and contract drawings should include provisions for unforeseen conditions which may require that the intake structure be founded at a lower elevation in order to reach competent rock.

3-3. Loads

The following forces are typical of those that may be required in the stability and stress analysis:

a. Dead load. The dead loads considered should include the weight of the structure and appurtenances such as gates, trashracks, bridges, and other attached features.

b. Hydrostatic. The hydrostatic loads against the structure should include internal and external pressures for all design operating conditions as well as for any construction conditions relevant to intake structures designed for diversion.

c. Uplift. Uplift pressure due to headwater exists along the structure-foundation interface, within the foundation below the base, and through any cross section within the structure. Uplift pressure is present within the cracks, pores, joints, and seams in the concrete and foundation material. Uplift at the base should be assumed to be 100 percent of the reservoir pressure over 100 percent of the base area. At internal planes, uplift shall be assumed to vary linearly from the hydrostatic head at the external surface of the intake structure to the hydrostatic head at any internal surface. Uplift pressures should be applied over 100 percent of the area of the plane and are assumed to remain unchanged during an earthquake.

d. Earth and silt. For structures within the dam embankment, earth pressures should be included in the design. Silt pressures are included where sediment buildup around the intake structure can be expected. The silt and earth material may or may not be submerged. The design should include evaluation of the site for liquefaction. The magnitudes of earth and silt pressures are discussed in EM 1110-2-2502.

e. Temperature. Temperature rises and cracking resulting from cement hydration are a concern only in intake structures with large massive concrete sections. Temperature rises caused by cement hydration can cause significant cracking. Cracking can be minimized and controlled through temperature control of mix, lift heights, insulation, and use of reinforcement steel. Temperature control measures are discussed in greater detail in Chapter 6, paragraph 6-4.

f. Earthquake forces. Chapter 4 presents criteria and guidance for determining earthquake forces.

g. Wind pressure. Wind loads shall be applied to the structure in accordance with American Society of Civil Engineers (ASCE) 7 (ASCE 1995). Wind loads will also be applied to the appurtenant structures as applicable.

h. Ice pressures. In locations where ice is a design consideration, the ice pressure should be applied in combination with operation and maintenance conditions. EM 1110-2-1612 furnishes guidance for magnitude and application of ice loads.

i. Debris and trash. Loadings on the structure resulting from debris and trash will depend on the nature of the trash burden in the reservoir, maximum hydraulic differential created by debris buildup on trashracks, the structure layout and operation, and other factors. Chapter 5 further discusses debris loading.

j. Wave pressure. Wave pressures will be determined from the fetch of the reservoir as related to the intake structure and the wind velocity and duration. The *Shore Protection Manual* (1984) provides information relating to wave forces.

k. Operation and maintenance loads. Cranes, trucks, stoplog and bulkhead installation and storage, and other maintenance equipment are loadings for consideration.

3-4. Load Conditions

a. General. The loading conditions provided in Table 3-1 generally apply for checking the stability and structural design of an intake structure. The loading cases for a specific intake structure should be chosen as applicable from the lists below. Specific operational and site conditions from construction through project life and structure configuration may require that the following conditions be modified or that additional analysis of conditions be made.

b. Basic loading conditions descriptions. Specific operational and site conditions from construction through project life and structure configuration may require that the stability loading conditions be modified, or that additional analysis of conditions be made. The loading conditions of Table 3-1 are described below.

(1) Loading Condition U1 - normal pool, all gates open.

- Dead load of structure.
- Reservoir at normal operating pool, annual mean maximum pool elevation with a 2-year return period.
- Earth load (if any).
- Ice loads, if applicable.
- Uplift.
- Water surface inside structure drawn down to hydraulic gradient with all gates fully open.
- Wave loads, if applicable.

Table 3-1
Intake Tower Loading Condition Classification

Load Case Number	Loading Description	Loading Condition Classification
U1	Normal Pool, All Gates Open	Usual
U1	Normal Pool, All Gates Open	Usual
U2	Normal Pool, One or More Gates Closed	Usual
U3	Normal Pool, All Gates Closed	Usual
U4	Normal Pool with Silt	Usual
U5	Minimum Pool	Usual
UN1	Infrequent Flood, All Gates Open	U/UN/E
UN2	Infrequent Flood, One or More Gates Closed	U/UN/E
UN3	Infrequent Flood, All Gates Closed	U/UN/E
UN4	Construction	Unusual
UN5	Diversion	Unusual
UN7	Maintenance Bulkheads in Place	Unusual
UN8	Operating Basis Earthquake	Unusual
E1	Maximum Design Earthquake	Extreme
E2	Maximum Design Flood	Extreme

Note: U = Usual; UN = Unusual; E = Extreme.

(2) Loading Condition U2 - normal pool, one or more gates closed.

- Dead load of structure.
- Reservoir at normal operating pool.
- One or more gates closed with other gates fully open and water surface drawn down to hydraulic gradient in remainder of structure in combinations that produce the most unstable conditions.
- Earth load (if any).
- Ice loads, if applicable.
- Uplift.
- Wet well full of water upstream from closed gate.
- Wave loads, if applicable.

(3) Loading Condition U3 - normal pool, all gates closed.

- Dead load of structure.
- Reservoir at normal operating pool.
- Earth load (if any).
- Uplift.
- Wave loads, if applicable.

(4) Loading Condition U4 - loading conditions U1 through U3 with silt (if any).

(5) Loading Condition U5 - minimum pool.

- Reservoir empty or at minimum pool.
- Dead load of structure.
- Earth load (if any).
- Ice loads, if applicable.
- Wind load in the direction that would produce the most severe foundation pressures.
- Uplift.
- Wave loads, if applicable.

(6) Loading Conditions UN1 through UN3. Loading conditions UN1 through UN3 are the same as U1 through U3 except the reservoir level is at the infrequent flood stage (i.e., water is at the top of the spillway gates for gated spillways or at the spillway crest for flood-control projects with ungated spillways).

(7) Loading Condition UN4 - construction.

- Reservoir empty.
- Dead load of structure (partially or fully completed).
- Earth load (if any).
- Heavy construction equipment required on or near the structure during construction.
- Wind load in the direction that would produce the most severe foundation pressures.

(8) Loading Condition UN5 - diversion.

- Reservoir at maximum elevation expected during diversion.
- Dead load of structure at diversion level completion.
- Earth load (if any).
- Heavy construction equipment required on or near the structure.
- Wind load in the direction that would produce the most severe foundation pressures.

(9) Loading Condition UN7 - maintenance bulkheads in place.

- Bulkheads in place, no water in structure downstream of bulkheads.
- Dead load of structure.

- Reservoir at maximum pool level at which bulkheads are used.
- Earth loads (if any).

- Uplift.

(10) Loading Condition UN8 - operating basis earthquake (OBE).

- OBE for the most critical of the conditions U1 through U5 with the reservoir at the elevation that is likely to exist coincident with the selected earthquake event.

- No ice.

(11) Loading Condition E1 - maximum design earthquake (MDE).

- MDE for the most critical of the conditions U1 through U5 with the reservoir at the elevation that is likely to exist coincident with the selected earthquake event.

- No ice.

(12) Loading Condition E2 - maximum design flood (MDF).

- Pool at probable maximum flood (PMF) elevation.

- All gates opened or closed, depending on project operating criteria.

3-5. Stability Analysis

a. General requirements. The basic requirements for the stability of an intake structure and other outlet works structures are described in EM 1110-2-2502. In summary:

(1) Outlet works structures should be safe against rotational instability at the base, at any plane below the base, and at any horizontal plane within the structure.

(2) Outlet works structures should be safe against sliding on any plane within the structure, at the base, or on any rock seam within the foundation.

(3) Outlet works structures should be safe against foundation bearing failures.

3-6. Structural Design

All parts of the intake structure should be designed to meet the strength and serviceability requirements outlined in EM 1110-2-2104. Load factors should be in accordance with EM 1110-2-2104 unless otherwise indicated (Refer to Appendix B for seismic loading condition strength requirements). The reinforced concrete elements of the structure should be designed to withstand the loading conditions given in paragraph 3-4. Additional loading conditions may be required to account for site-specific conditions not covered by paragraph 3-4.